TIME DOMAIN ELECTROMAGNETIC SURVEYS FOR ASSISTING IN DETERMINING THE GROUNDWATER RESOURCES ON KEALAKEKUA RANCH LTD PROPERTY ISLAND OF HAWAII

Project Number 5069

March 2007

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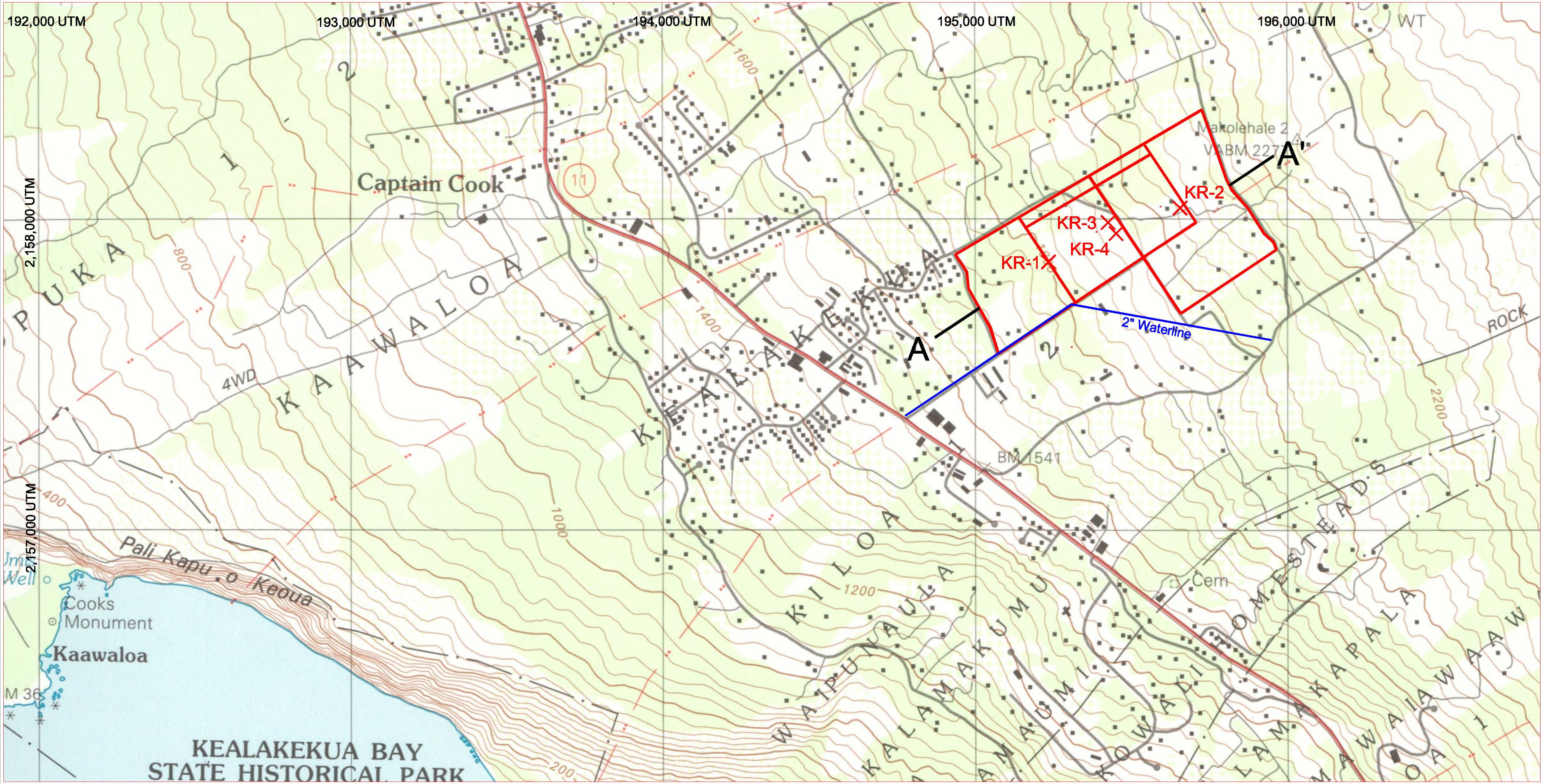
1.0 INTRODUCTION

This report contains the procedures and results of surface Time Domain Electromagnetic (TDEM) geophysical surveys performed for groundwater resource evaluation on Kealakekua Ranch Ltd. property located on the Kealakekua Tract on the Island of Hawaii. ZAPATA ENGINEERING Blackhawk Division (Blackhawk) conducted the surveys from January 31 to February 3, 2007 for Pa'ahana Enterprises LLC (PEL) of Kealakekua, Hawaii and Kealakekua Ranch, Ltd. (KRL) of Captain Cook, Hawaii.

The main objective of the TDEM surveys was to explore for basal and high-level groundwater occurrences located on KRL property above the Kealakekua Ranch Center. The surveys were conducted at four TDEM sites to help determine the optimum location for a future groundwater well above the Mamalahoa Highway in Captain Cook, Hawaii. Figure 1-1 shows the locations of TDEM soundings taken during the surveys on KRL property.

TDEM is a geophysical method that determines from the surface the geoelectric section (resistivity layering) of the subsurface. From the geoelectric section, information about geology and water quality can be inferred. This is possible because the electrical resistivity of the earth depends on lithology, porosity, the degree of saturation, and concentration of dissolved solids in the groundwater. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths.

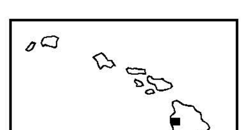


Explanation

A-A' Section Line

KR-2 × 2007 TDEM Sounding

N



0 1000 2000

Scale in Feet

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Kealakekua Ranch, LTD

Geophysical TDEM Survey
Location Map
KRL Property
Captain Cook, Hawaii

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2.0 GEOLOGY/HYDROGEOLOGY

Groundwater resources occur on the Hawaiian Islands basically in two modes:

- In a basal mode where a lens of fresh water floats on seawater, and
- In a high-level mode where the fresh groundwater occurrence is controlled by damming structures (i.e. intrusives, dikes, etc).

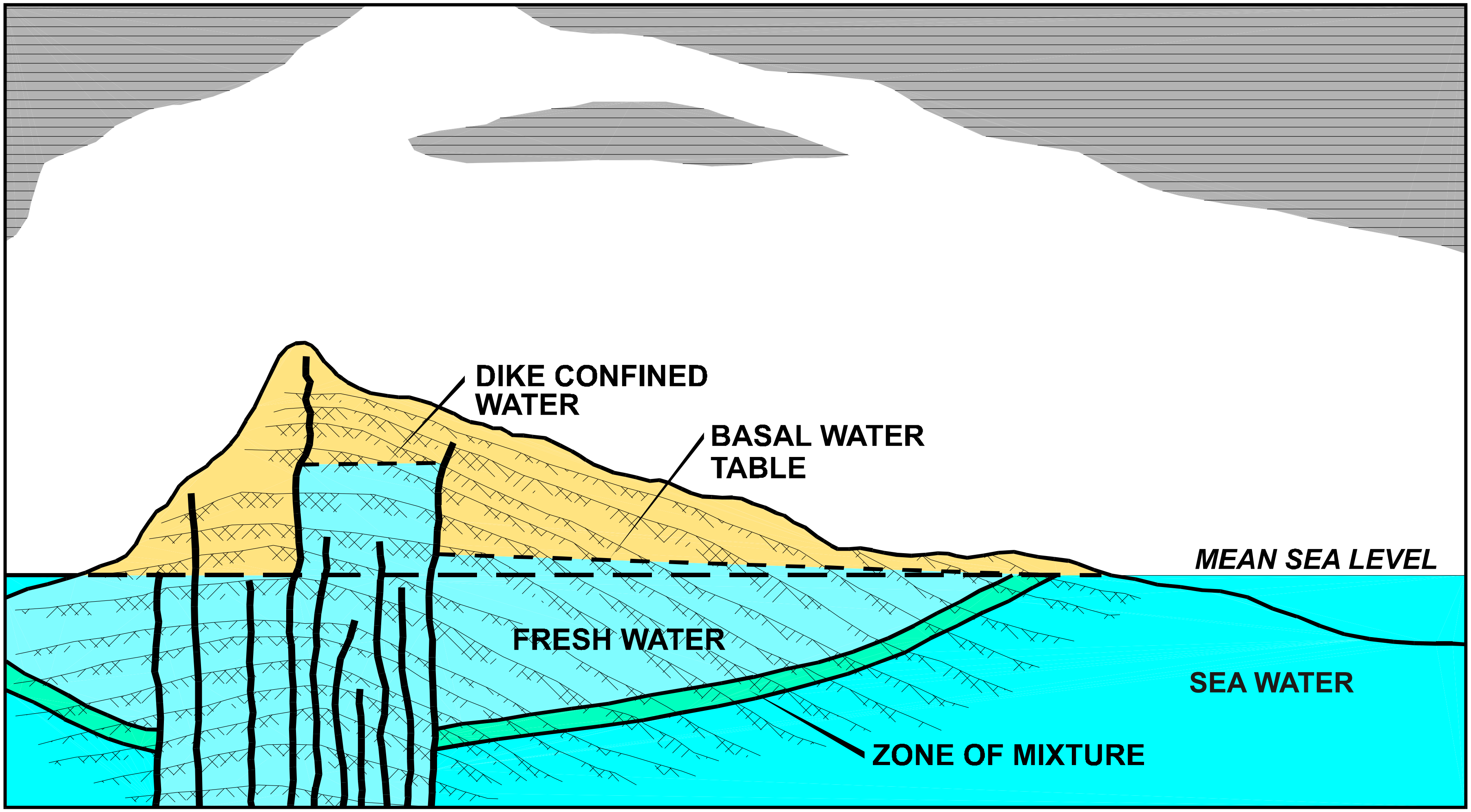
The basic geologic and hydrologic framework of the Island of Hawaii and the two modes of groundwater occurrences are illustrated in Figure 2-1. Fresh groundwater may also occur in areas between these two modes, but production is expected to be highly variable. TDEM surveys previously run on Hawaii have reliably mapped the basal mode groundwater occurrence and the boundary between fresh water in the basal mode and high-level water occurrences.

Basal mode groundwater is resting approximately at sea level near the ocean surrounding the Island of Hawaii. This is generally due to the fact that the volcanic rocks which comprise the island allow rainfall to percolate with little impedance directly downward through the rock mass (reference Figure 2-1). The fresh water floats directly on seawater encroaching from the ocean. Fresh water flows laterally toward the ocean causing the fresh water lens to be thinner near the ocean. When groundwater is under conditions of static equilibrium, the Ghyben-Herzberg Principle states that for every one foot of fresh water above sea level, approximately 40 feet of fresh water will exist below sea level as shown in Figure 2-2. The transition from fresh water to seawater at depth may be relatively sharp (i.e. occurring over several tens of feet) or more gradual, depending upon hydrologic flux, horizontal and vertical permeability contrast, and other geologic factors. It is assumed, when resolving TDEM sounding data, that seawater saturated volcanics begin at the midpoint of the transition zone.

TDEM surveys are utilized to map the resistivity stratification of the subsurface. From numerous previous TDEM surveys and calibration at well sites, characteristic ranges of subsurface resistivities have been derived for the geologic/hydrologic units shown in Figure 2-3. Some overlap in resistivity occurs between the units; however, other factors (such as elevation) can be used to help separate the units. Therefore the main geologic/hydrologic units that can be derived from TDEM surveys are:

- Depth to seawater saturated volcanic rocks. This occurs in basal mode situations, and by using the Ghyben-Herzberg Principle, the thickness of the basal fresh water lens can be calculated.
- Weathered volcanic layers (laterite). These lower resistivity units are generally relatively thin layers that occur mainly at or near the ground surface.
- Clay poor and fresh water saturated volcanic rocks. These formations generally exhibit high resistivity values. Note that the extent of fresh water saturation is normally based on geographic and elevation information, and that fresh water cannot be directly detected in the TDEM data.

Groundwater damming structures (i.e. intrusives, dikes) are inferred with TDEM data by uncharacteristic sounding curves (distorted by 2-dimensional structures), and by soundings that transition between detection of seawater at depth (indicating basal mode groundwater) and soundings that do not detect seawater at depth and map high resistivities to significant depths below sea level (indicating high-level groundwater).



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Schematic Hydrogeologic Cross Section
Island of Hawaii

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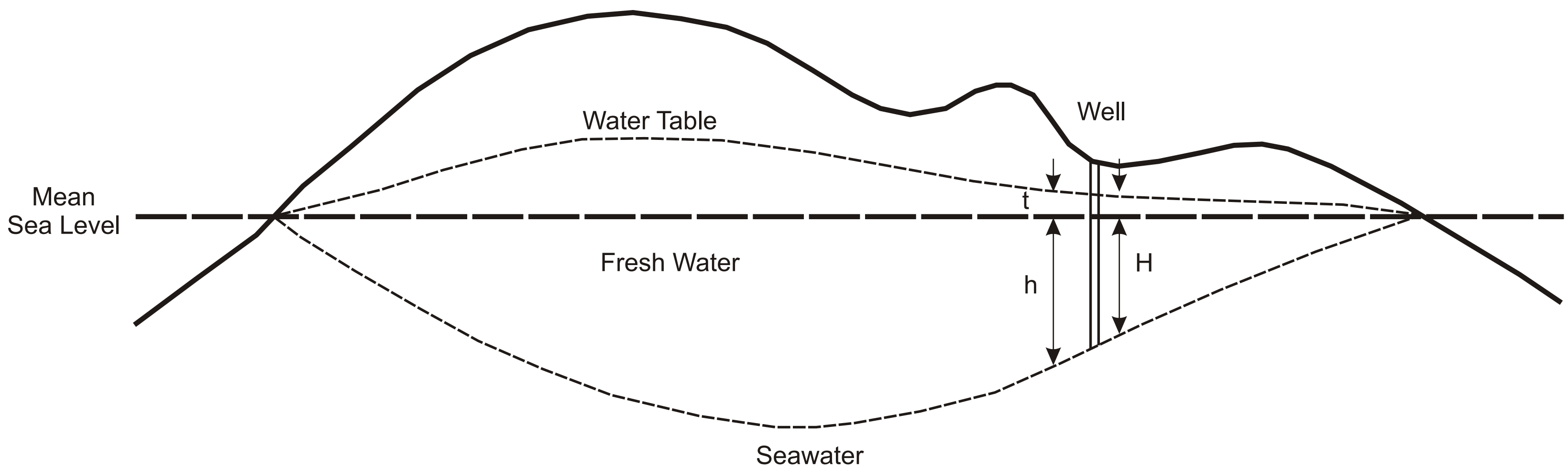
5069	March, 2007	HJV	RJB	No Scale	2-1



$$t = 1/40\ (h)$$

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Illustration of the Ghyben-Herzberg Principle

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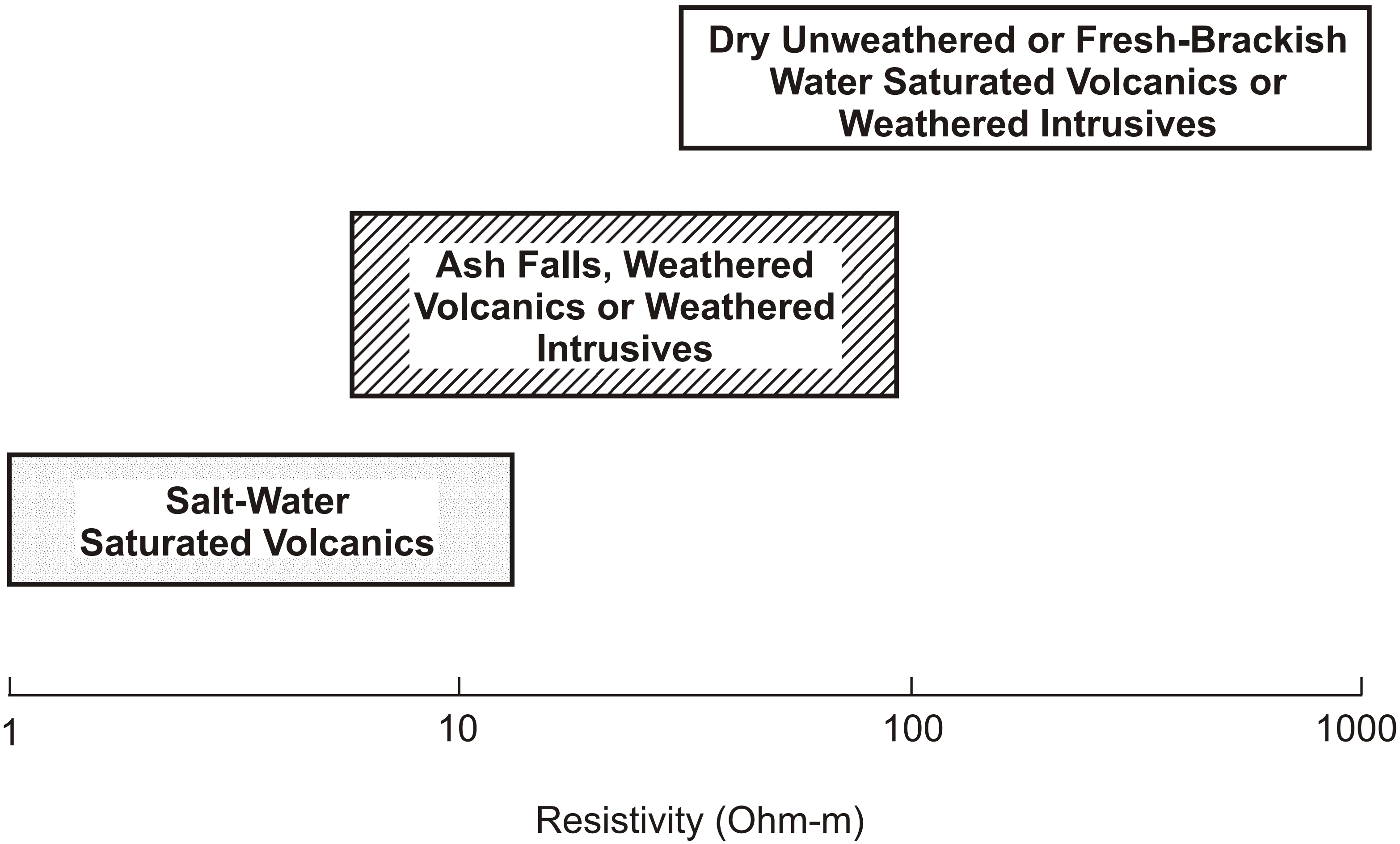

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Characteristic Resistivity Ranges
Island of Hawaii

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3.0 DATA ACQUISITION AND LOGISTICS

Blackhawk mobilized a field crew consisting of a project geophysicist and geophysical technician to perform the geophysical surveys on the KRL property. The Blackhawk field personnel and TDEM equipment were mobilized from Golden, Colorado to Kailua-Kona, Hawaii. During the fieldwork PEL personnel provided project direction, oversight and maps while KRL personnel provided site access to the property. A daily log of field activities during the TDEM surveys is presented in Table 3-1.

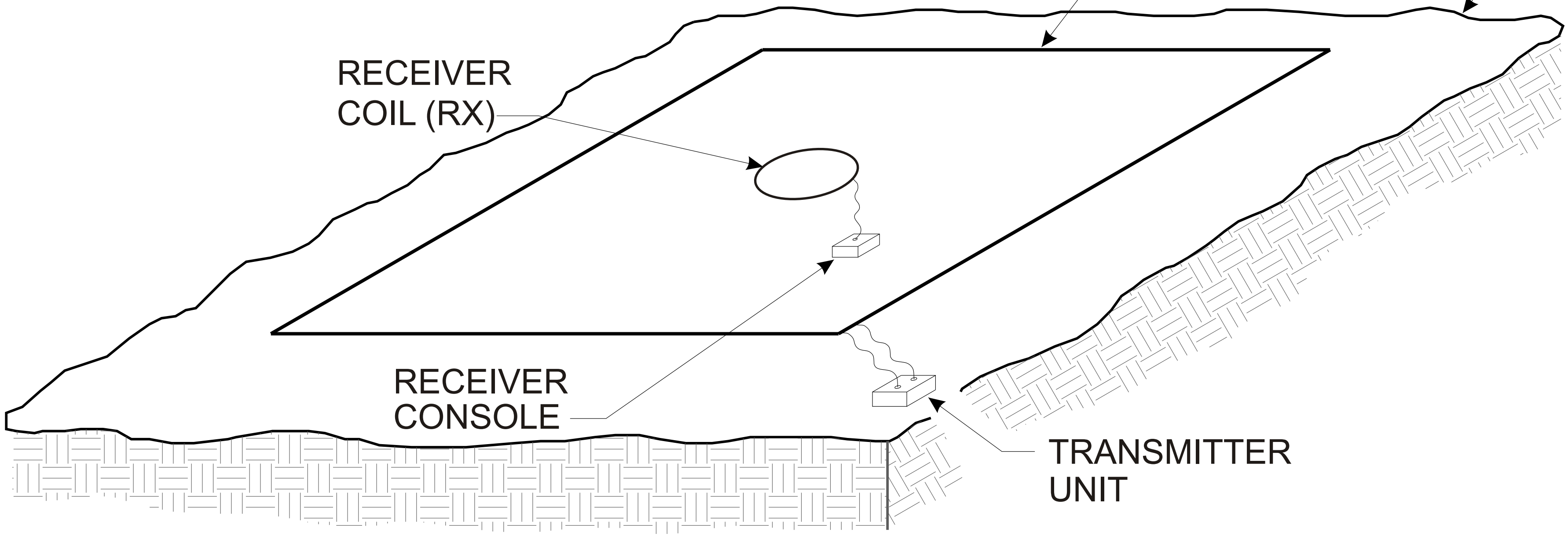
The geophysical equipment utilized for the TDEM surveys was the Geonics EM37 system. The EM37 system consists of both a portable motor-generator powered transmitter and a PROTEM digital receiver. The main purpose of the TDEM measurements is to derive both the vertical and lateral variations in the geoelectric section (resistivity) of the subsurface. To accomplish this, the TDEM measurements were acquired using a central-loop array at each sounding site. The transmitter loops were constructed using 12-gauge insulated copper wire laid on the ground surface, as illustrated in Figure 3-1. Due to road access and limited space in the subdivision, rectangular transmitter loops were utilized instead of square loops; therefore, the loops varied in dimensions from about 1,000 ft by 1,700 ft (Sounding KR-1) to about 1,100 ft by 1,800 ft for Sounding KR-2. The rectangular wire-loop configurations did not affect the exploration depth of the soundings. The motor-generator and transmitter were placed at a corner of the wire-loop and square-wave current pulses were driven through the wire using a current ranging from 10 to 11 amperes. The current pulses induce eddy current flow in the subsurface of the ground. A receiver coil (1-meter diameter) attached to the PROTEM receiver was positioned in the center of the wire-loop and used to record the decay of the secondary magnetic field due to the eddy currents induced in the subsurface. The effective exploration depth of a 1,500 ft by 1,500 ft transmitter wire-loop array has been determined to be approximately 3,000 ft. Greater exploration depths are reached with larger transmitter wire-loops and several factors that affect the depth of investigation include ground resistivity (ohm-m) and surrounding cultural interference (i.e. 60-cycle powerline, pipelines, etc).

The TDEM data acquired at each sounding consisted of measurements utilizing several receiver gain settings and two transmitter frequencies in order to ensure data quality and to obtain data over the longest possible time interval. The sounding data were recorded at base frequencies of 3 Hz and 30 Hz. For data quality control (QC) purposes, additional offset data sets were collected at designated locations (typically 100 ft) from the center of each sounding, for comparison to the central-loop data. The data from each sounding were stored in a solid-state memory logger in the PROTEM receiver and transferred at the end of each day to a PC for processing. The data collected at TDEM Sounding KR-2 were of excellent quality. Although efforts were made to position the transmitter wire-loops and center receiver locations away from known cultural interferences (i.e. pipelines, etc.), Soundings KR-1, KR-3 and KR-4 were determined to be distorted and unusable in the interpretation. A technical note describing the principles of TDEM with case histories is given in Appendix A.

The center and corners of each transmitter wire-loop were registered to existing paved road intersections (Kiloa Road and Kinue Road) located on the property. Other landmark features, such as pipelines and houses, were also used to locate the wire-loops on the map with a compass and hip-chain. In addition, a hand-held global positioning system (GPS) was utilized to map both the receiver and transmitter locations of each sounding. The GPS information was used to position each loop center on the geo-referenced topographic map and the elevation was subsequently taken from that position. A total of four soundings were measured on the KRL property during the three days of fieldwork. The GPS coordinates and elevations of the TDEM soundings are given in Table 3-2 in Appendix B.

Table 3-1
Daily Log of Field Activities
KRL Property TDEM Survey

Date (2007)	Activity
January 16	Ship TDEM geophysical equipment from Golden, CO to Kona, HI.
January 22	Mobilize Blackhawk field personnel from Golden, CO to Kona, HI.
January 23-30	Unpack TDEM geophysical equipment at Kona Beach Hotel. Test motor-generator and organize equipment into 4WD vehicle. Field work on other TDEM projects in Hawaii.
January 31	Meet with PEL and KRL field representatives at Kealakekua Ranch Center to discuss project. Begin geophysical survey. Lay out and collect TDEM data on Sounding KR-1 (open field). Download data to PC and perform preliminary data analysis. Discuss results with PEL.
February 1	Lay out and collect data on Sounding KR-2 (coffee trees). Download data to PC and perform preliminary data analysis. Discuss results with PEL. Decision made by PEL to collect data on GF property.
February 2	Work on GF project.
February 3	Lay out and collect data on Soundings KR-3 and 4 (coffee trees). Download data to PC and perform preliminary data analysis. Discuss results with PEL. Finish KRL project.
February 4-February 12	Fieldwork on other projects in Hawaii. Deliver TDEM equipment to FedEx at Kona Airport. Demobilize Blackhawk personnel from Kona, HI to Golden, CO.



BLACKHAWK A DIVISION OF ZAPATA ENGINEERING	Pa'ahana Enterprises LLC Kealakekua Ranch, LTD		Schematic layout of TDEM system with locations of TX and RX for Central Loop Array measurements

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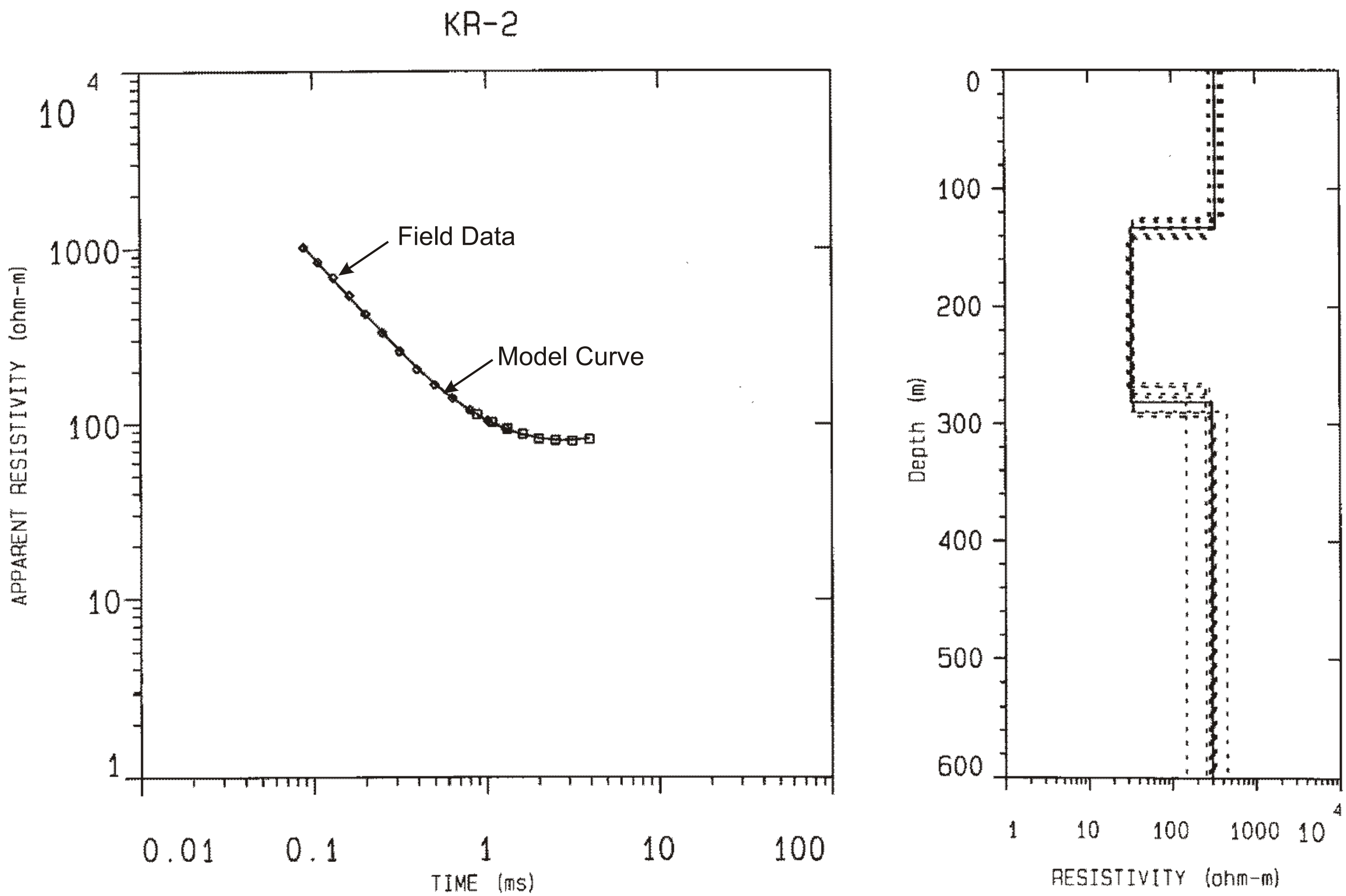
4.0 DATA PROCESSING

The field data collected for each TDEM sounding was transferred from the Geonics PROTEM digital receiver to a PC for editing and processing. Processing of the TDEM data starts with averaging of the electromotive forces recorded at positive and negative receiver polarities. Next, the measurements collected at the two base frequencies (3 and 30 Hz) and different amplifier gains are combined to give one voltage decay curve (transient). The electromotive forces in the various time gates of the decay curves were subsequently entered into the TEMIXXL (Interpex Ltd) inversion program to obtain a one-dimensional (1-D) geoelectric section that best matches the observed decay curve.

The TEMIXXL inversion program requires an initial model of the geoelectric section measured. The initial model includes the number of layers and the resistivities and thickness for each of the layers. This model is usually derived from general knowledge of the geologic section or from data obtained from drill holes or electric logs. The inversion program is then allowed to adjust the layer thickness and the resistivities, so that the model curve converges to best fit the field data. The inversion program does not change the total number of layers within the model curve, but allows all other parameters to change freely or they can optionally be fixed constant. To determine the influence of the number of layers on the solution, separate inversions with a different number of layers are run. Subsequently, the model with the least number of layers that best fits the field data is used.

An example of the output of the inversion program is shown in Figure 4-1 for Sounding KR-2. This figure shows the measured data points (in terms of apparent resistivity) superimposed on a solid line on the left panel. The solid line represents the computed forward model for the geoelectric section on the right panel. This geoelectric section is the best match obtained by the inversion program. Figure 4-2 shows the tabulated inversion parameters consisting of measured data, computed data for best match solutions and an example of the table of inversion statistics. A three-layer inversion model is shown for Sounding KR-2. The model displays a relatively thick (437 ft) upper layer with high resistivity (330 ohm-m), overlying a second intermediate resistivity (32 ohm-m) layer. A third layer with resistivity of 297 ohm-m is interpreted in the section.

The interpreted geoelectric section derived from each TDEM sounding is not unique. The magnitude of each individual layer resistivity and thickness can normally be varied within a limited range with no significant change to the fit of the geoelectric model of the data. This variation is termed equivalence. An equivalence analysis was performed for each TDEM sounding. Figures 4-1 and 4-2 also show the equivalence analysis for Sounding KR-2. This sounding is typical of the TDEM data and shows a +/-5% equivalence in depth determinations and +/-10% in individual layer resistivities. The inversion results for each sounding of this project are given in Appendix B.



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Sounding KR-2
Example Inversion Output
Apparent Resistivity Curve
Captain Cook, Hawaii

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5069	March, 2007	HJV	RJB	No Scale	4-1

DATA SET: KR-2

CLIENT: Paahana Enterprises LLC
LOCATION: Captain Cook
COUNTY: Hawaii
PROJECT: Kealakekua Ranch, Ltd
LOOP SIZE: 480.000 m by 480.000 m
COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 2.0000 N: 3.0000

DATE: 02-01-07
SOUNDING: 2
ELEVATION: 621.70 m
EQUIPMENT: Geonics PROTEM
AZIMUTH:
TIME CONSTANT: NONE
SLOPE: 1.00

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 1.687 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			621.7	2040.0	
1	330.2	133.2	488.4	1602.3	0.403
2	32.22	147.8	340.6	1117.4	4.58
3	297.1				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	276.496	330.264	415.114
	2	29.040	32.221	34.669
	3	148.230	297.135	450.843
THICK	1	124.785	133.284	142.579
	2	122.921	147.812	166.478
DEPTH	1	124.785	133.284	142.579
	2	265.077	281.096	293.612

Equivalence Analysis

CURRENT: 10.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 6 RAMP TIME: 170.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	1320.6	1342.5	-1.65
2	1.06	950.7	968.4	-1.86
3	1.31	650.9	661.9	-1.69
4	1.61	428.0	433.3	-1.23
5	2.00	274.3	271.3	1.07
6	2.50	161.0	161.2	-0.119
7	3.14	93.17	91.60	1.67
8	3.95	50.78	50.16	1.21

CURRENT: 10.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 3 RAMP TIME: 170.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
9	0.0881	15533.7	15181.1	2.26
10	0.106	12859.2	12869.1	-0.0775
11	0.131	10467.2	10809.2	-3.26
12	0.161	8814.1	9021.5	-2.35
13	0.200	7402.1	7458.1	-0.755
14	0.250	6135.4	6080.1	0.900
15	0.314	4987.9	4884.8	2.06
16	0.395	3964.8	3855.7	2.75
17	0.499	3036.9	2958.1	2.59
18	0.631	2205.0	2194.0	0.498
19	0.799	1547.3	1560.8	-0.867
20	1.01	1055.4	1057.0	-0.149
21	1.28	679.5	683.5	-0.589

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

	P 1	P 2	P 3	T 1	T 2
P 1	0.72				
P 2	-0.09	0.95			
P 3	-0.02	-0.03	0.07		
T 1	0.08	0.03	0.01	0.97	
T 2	-0.14	-0.08	-0.13	0.05	0.85

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Sounding KR-2
Example of Tabulated Data
From Inversion
Captain Cook, Hawaii

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5069	March, 2007	HJV	RJB	No Scale	4-2

5.0 INTERPRETATION AND RESULTS

5.1 TDEM SOUNDING DATA

From each TDEM sounding, the geoelectric section of the subsurface is derived. The results of the one-dimensional (1-D) inversion of the individual TDEM soundings can be linked together (layers with similar resistivities) to create a 2-D geoelectric cross-section along a survey line. For this project, a total of four TDEM soundings were collected on the KRL property. One geoelectric cross-section was constructed from the TDEM survey data and is shown in Figure 1-2. The correlations established between geoelectric layers and lithologic units (reference Figure 2-3) were used to interpret the geoelectric cross-sections.

5.2 GEOELECTRIC CROSS-SECTION – LINE 1 (A-A')

Figure 5-1 shows the layered geoelectric cross-section interpreted from the TDEM data taken along Line 1. The TDEM soundings were positioned on KRL property above the Kealakekua Ranch Center and are situated in a west to east direction along the line (reference Figure 1-1). The transmitter wires for each of the soundings were located along the surface roads in the subdivision and were positioned, as best as possible, away from known cultural features (i.e. pipelines, etc.) in these areas. The center of Sounding KR-1 was located north of Kiloa Road in an open field at an elevation of 1,800 ft while the Sounding KR-2 center was located at 2,040 ft elevation in coffee trees above Kinue Road.

Although QC readings taken for Soundings KR-1, KR-3 and KR-4 did not detect distortion of the TDEM data, these soundings were deemed to be distorted by possible undetected cultural features (i.e. pipelines, etc.). The second layer with abnormally low interpreted resistivity values (1.0 to 1.5 ohm-m) is not geologically reasonable and indicates that this sounding is distorted. Therefore, these soundings are questioned in the interpretation. The third layer which extends from an elevation of over 1,000 feet above sea level to the maximum exploration depth of over 1,000 feet below sea level and has an interpreted resistivity of 26 ohm-m is also not geologically reasonable. The causes of distortion in this portion of the sounding may be the result of:

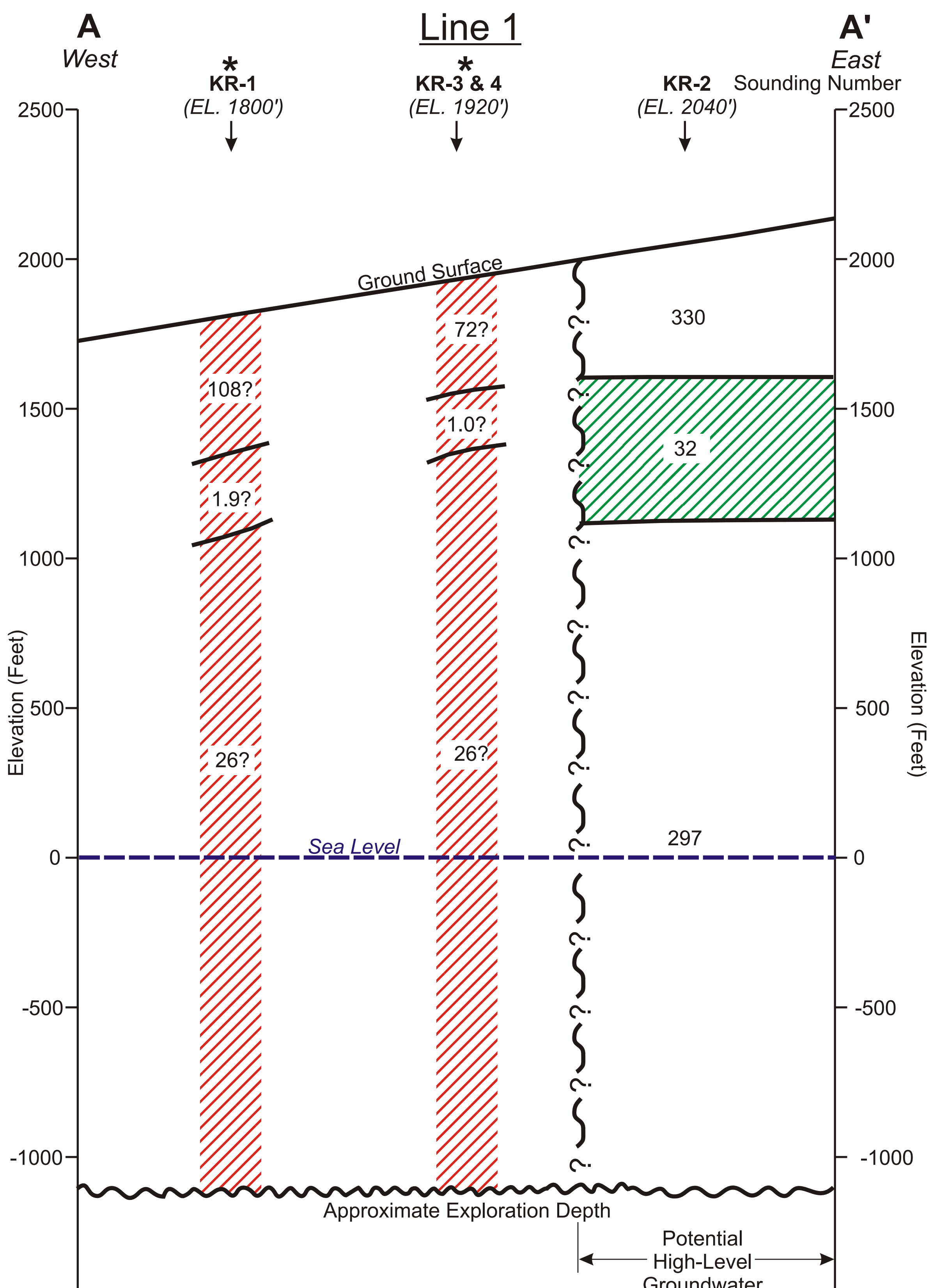
- Surface cultural features (i.e. pipelines, etc.) in these areas, or
- 2-dimensional (2-D) geologic structures (i.e., high angle dikes or clay layers) at depth in the section.

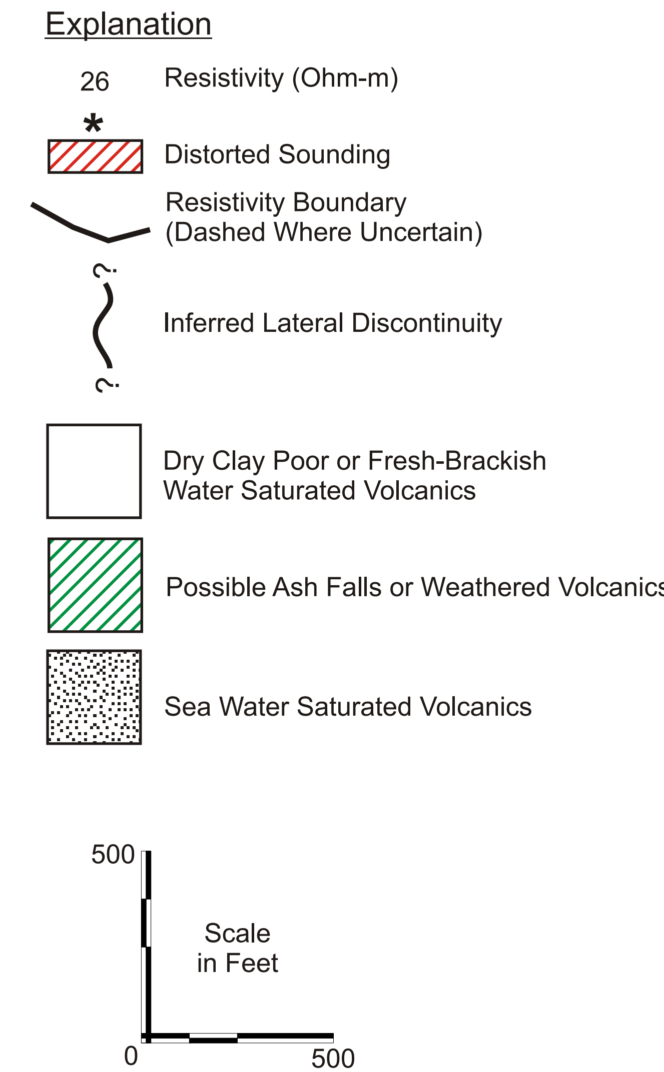
The occurrence of interpreted intermediate resistivities (26 ohm-m in Soundings KR1, 3, and 4) both above and below sea level has been indicative of a transition zone from basal groundwater to high-level groundwater in similar surveys within the Hawaiian Islands. It is possible that 2-D structures in this zone are distorting the TDEM soundings. The 2-D structures may also be causing groundwater damming. The exact nature of these structures is unknown but they may consist of high angle volcanic dikes and/or weathered zones.

A three-layer section is interpreted beneath Sounding KR-2. The upper layer in the cross-section exhibits a high resistivity of 330 ohm-m and is interpreted as dry clay poor volcanic formations above sea level. The second layer in the section displays an intermediate resistivity (32 ohm-m) with thickness of about 485 ft and is interpreted to be influenced by layers (i.e. ash fall, clay, etc.) in this portion of the geologic section. The third layer exhibits a high resistivity value (297 ohm-m) throughout the effective exploration depth of the measurement (approximately 1,000 ft below sea level). Therefore, this sounding is interpreted to be in an area with potential high-level groundwater. It is located inland of the geologic/hydrologic damming structure (i.e. dikes, etc) that likely occurs down slope towards the west. Because of the distorted results from Soundings KR-1, KR-3 and KR-4 and the limited TDEM data density in this area, the exact position of the geologic structure or structures is uncertain.

5.3 Hydrogeologic Interpretation

The TDEM data from the survey is further summarized on the interpretation map shown in Figure 5-2. On this map Sounding KR-2 (yellow) exhibits a high resistivity value (297 ohm-m) which was interpreted to the effective exploration depth of the sounding (about 1,000 ft below sea level). Therefore, the potential for high-level groundwater exists in the area beneath this sounding.





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Geoelectric Cross-Section
from 1-D TDEM Inversions
Line 1 - Transect A-A'
KRL Property
Captain Cook, Hawaii

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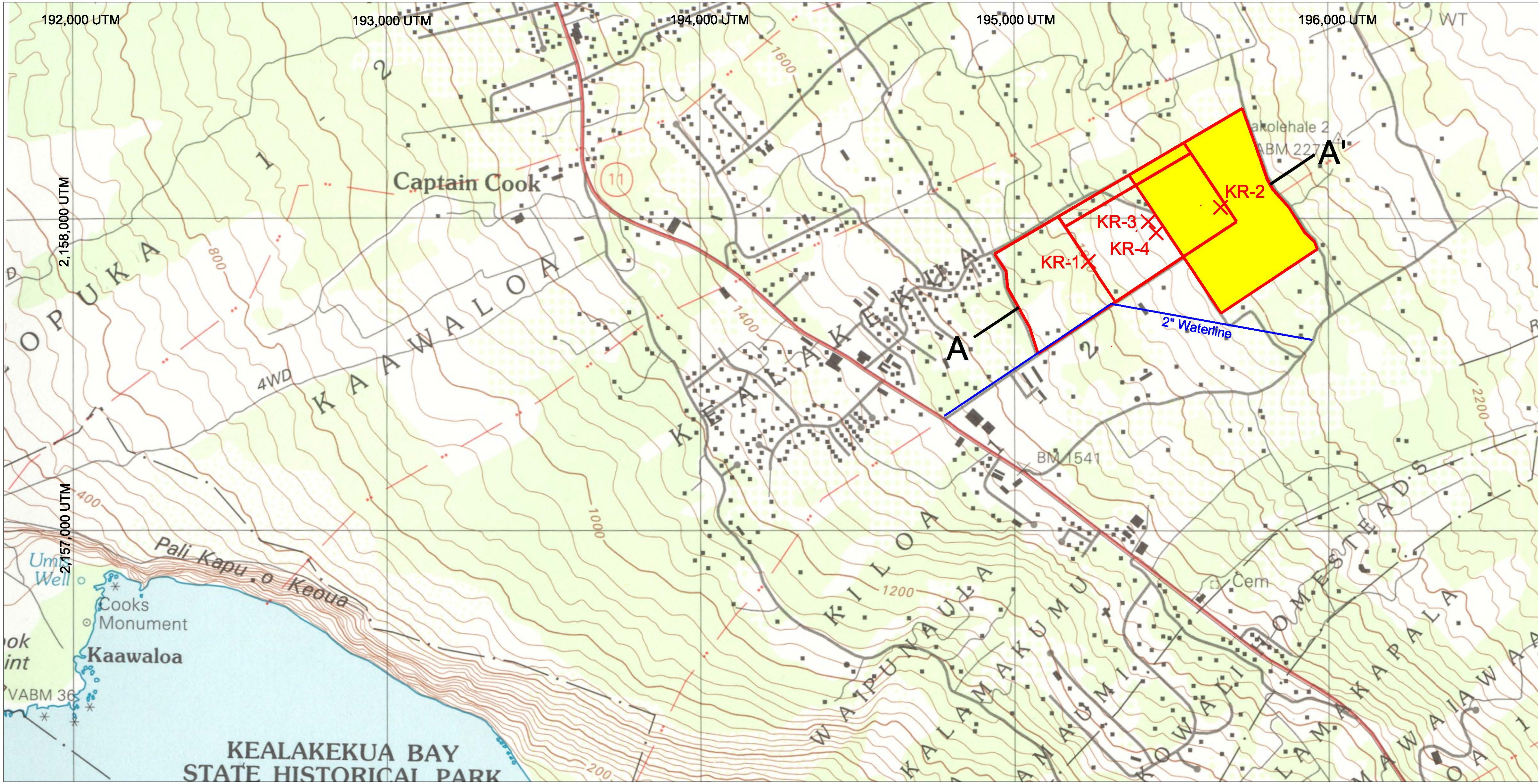


Explanation

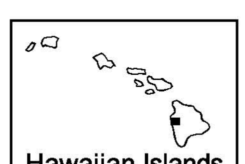
A-A' Section Line

KR-2 2007 TDEM Sounding

Sounding in which Groundwater is expected to be controlled by Geologic Structure (Potential High-Level Water)

0 1000 2000
Scale in Feet

N



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Geophysical TDEM Survey Summary Interpretation Map
KRL Property
Captain Cook, Hawaii

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5069	March, 2007	HJV	RJB	1"=1000'	5-2

6.0 CONCLUSIONS AND RECOMMENDATIONS

The main objective of the TDEM surveys on the KRL property on Hawaii was to obtain geophysical data which would aid in the mapping of groundwater resources in the subdivision above the Kealakekua Ranch Center.

The results from the TDEM soundings are shown on the summary map in Figure 5-2. The data from Soundings KR-1, KR-3 and KR-4 appear to be distorted by cultural features (i.e. pipelines, etc.) and possible 2-dimensional geologic structures (i.e. high angle intrusives, etc). The potential for high-level groundwater is expected to exist beneath Sounding KR-2. Because of the distorted TDEM data and limited access in this area, the exact position of potential groundwater damming structures was not determined, and therefore the optimum location (lowest elevation) for a high-level groundwater well was not identified.

During the planning stages prior to these surveys, substantial efforts were made to find other locations (open areas) for additional TDEM soundings both directly above and below the Kealakekua Ranch Center. But, due to numerous cultural features (pipelines, houses, etc) that were identified, there were no areas found that would lend themselves to additional TDEM soundings. However, from the topography map of the area, there appears to be an open area directly below the Kealakekua Ranch Center and Mamalahoa Highway (at about 1,400 ft elevation) that may be an area to place an additional TDEM sounding. This area may be suitable for a 1,000 ft by 1,000 ft transmitter loop which could aid in the determination of the groundwater regime.

7.0 CERTIFICATION AND DISCLAIMER

All geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by ZAPATAENGINEERING P.A. Blackhawk Division, Senior Geophysicists and Engineers.

This geophysical investigation was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.

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